Characteristics of Ozone Episodes during SCCCAMP 1985

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ABSTRACT

Extensive meteorological and air chemistry measurements were obtained along the Ventura and Santa Barbara county coastal areas in California during four 2–3 day case studies conducted during the September–October 1985 South-Central Coast Cooperative Aerometric Monitoring Program (SCCCAMP 1985). An overview of the characteristics of ozone episodes during these four case studies is given, showing that the episodes are associated with warm, high pressure systems with light winds. In the absence of easterly winds, the observed ozone in the region is primarily due to local sources. At other times, easterly wind components transport ozone and its precursors from large source regions to the east (i.e., Los Angeles County). This transport sometimes occurs in inland valleys at elevations up to 600 m, and sometimes occurs over the ocean near the surface. Local sea breezes, mesoscale eddies, and terrain-generated winds often cause complex flow patterns and recirculation of pollutants.

1. Introduction

The objective of the South-Central Coast Cooperative Aerometric Monitoring Program (SCCCAMP 1985) was to provide an extensive database to be used for analyzing the causes of ozone formation in the region. The SCCCAMP region consists of the counties of Ventura and Santa Barbara and is located immediately to the west of Los Angeles County. Figure 1 contains a map of the region, showing the topography and the major geographic features. The entire region, with the exception of the northern parts of Santa Barbara and Ventura counties, exhibits numerous days with exceedances of the 1-h regulatory standard (120 ppb) per year. The air pollution potential in the region is high due to high temperatures, clear skies, limited vertical mixing, light and variable winds, and blocking by mountains. There are many significant local air pollution sources in the region, although the sources in adjacent Los Angeles County are much larger. Geogenic oil and gas that seep into the area emit methane and other gases into the atmosphere. In addition, there are 25 oil and gas platforms in the channel area with about five more platforms planned in the next decade. In fact, the overall SCCCAMP study is driven by the need to answer the question whether the planned oil and gas platforms will adversely affect local air quality.

Previous data collection efforts in the region were lacking one or more important components. It was decided to conduct a major five-week field study (SCCCAMP) in September and October 1985, to provide a comprehensive database for the development and evaluation of photochemical simulation models (Dabberdt and Viezee 1987). There were two types of measurements: 1) routine measurements taken throughout the five-week period, and 2) intensive measurements taken only during the four 2–3 day intensive case study periods, which were selected on the basis of daily forecasts of weather and air pollution potential. Routine data are listed in the following:

- standard National Weather Service (NWS) observations.
- A mesoscale network of wind observations.
- Mixing-depth observations by 11 Doppler Acoustic Wind Sounders (DAWS).
- Surface air chemistry at many sites.

Intensive case study data included the previous list, plus the special data listed in the following:

- wind data over the channel from a dual-Doppler radar system.
- Mixing depth observations by four aircraft.
- Aerometric observations by three aircraft.
- Tracer gas releases and tracking by means of aircraft and a network of surface monitors.

All data have been placed in a consistent data archive that is made available through the National Technical Information Service (NTIS).

Detailed descriptions of the data collection efforts during the intensive case study periods are given by Dabberdt and Viezee (1987) and Viezee et al. (1987),

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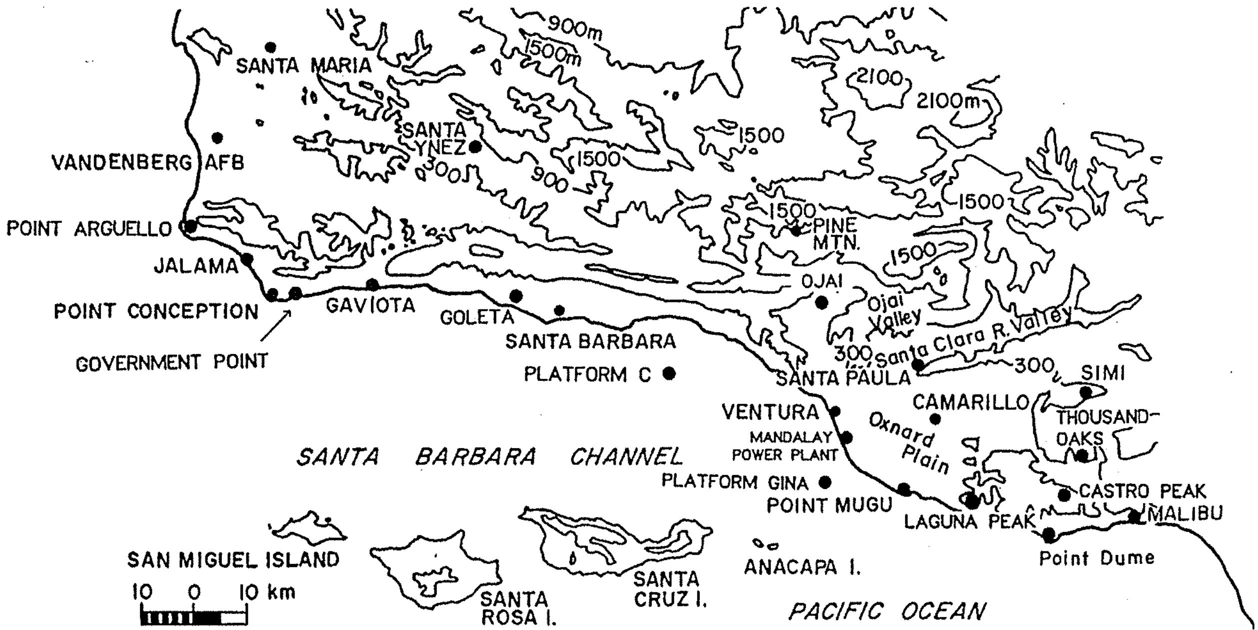


FIG. 1. Topographic map of SCCCAMP region, with a few major towns and cities and geographic features shown (from Dabberdt and Viezee 1987). Los Angeles County is adjacent to the eastern part of this map. Contour elevations are given in meters.

and a summary is given by Hanna et al. (1991) in the first paper in this special issue. Additional discussions of the data and the results of various data analysis projects can be found in other papers in this issue. For example, the results of the tracer experiments are described by Strimaitis et al. (1991).

This paper presents an overview of analyses of the data from the four intensive case study periods. First, graphs and tables of meteorological and air chemistry observations are presented for the entire five-week period, illustrating typical variations in these parameters with time and geographic location. Similarities and differences among the four intensive case study periods are illustrated. Then the intensive case studies are discussed individually, covering the various components of the study, including the characteristics of transport, dispersion, and air pollution concentrations and fluxes during the period. Emphasis is on identifying meteorological conditions associated with high ozone concentrations.

2. Overview of characteristics of five-week SCCCAMP 1985 experiment

Before describing the four individual case studies, it is instructive to present some graphs illustrating the variation of observed parameters during the entire five-week period. Figure 2 illustrates the day to day variation of mixing depth, wind direction, and 850-mb temperature in the region, and Figure 3 illustrates the concurrent variation of ozone concentrations at several stations (Dabberdt and Viezee 1987). It is seen in Fig. 2 that relatively cool air with high mixing depths and westerly flow occurred during most of the period, especially during the first two weeks of the experiment. However, during the four case study periods the air warmed by 5°–10°C, the mixing depth dropped to 300 m or less, and the flow at elevations of a few hundred meters turned to the east. The time series in Fig. 3 of the daily maximum hourly ozone concentrations at the surface at coastal and inland sites show a general increase in ozone concentrations by a factor of two or more during the case study periods. Figure 4 continues this analysis by presenting time series of daily ozone maximum for three different pairings of stations, showing differences in ozone concentrations with respect to west to east position on the coast (top), to offshore and inland position (middle), and to sea-level or mountaintop elevation (bottom). The monitor station locations are given in Fig. 1. It is seen that case study period 4 (2–4 October) was different from the other three periods in the sense that the air mass containing ozone pollution was located at low levels over the water in period 4. In contrast, during the other periods, the ozone concentrations tended to be higher inland than offshore, and higher on the mountaintops than at sea level. It is interesting that the peak concentrations along the coastline during each case study period show little variation from west to east, although the time duration of high concentrations is shorter in the western portion of the region, probably due to its greater distance from the pollution source region.

It is useful to attempt to determine causalities during the SCCCAMP 1985 period. For example, even though

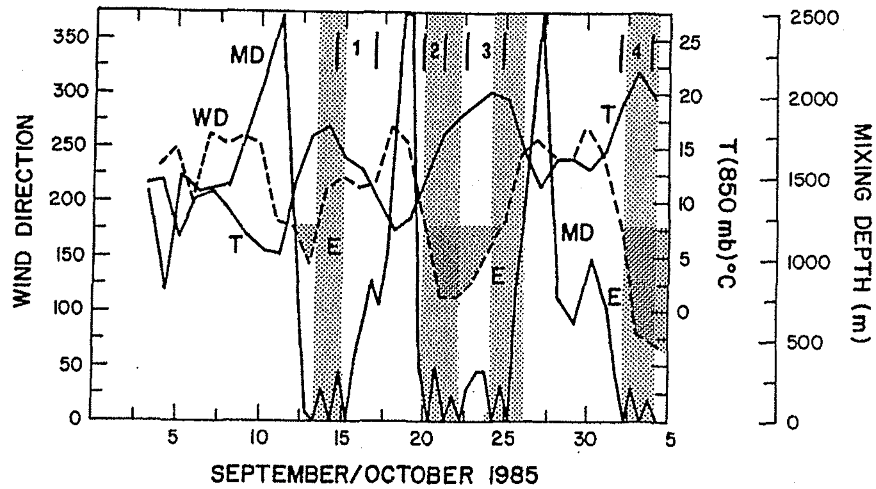


FIG. 2. Daily variation of mixing depth (MD) and 850-mb temperature (T) at Vandenberg (western portion of region) and morning wind direction (WD) at Laguna Peak (450 m MSL in the eastern portion of the region); shading indicates periods with easterly wind component. The intensive case study periods are indicated by numbers 1, 2, 3, and 4. Figure taken from Dabberdt and Viezee (1987).

high ozone concentrations are known to be well correlated with high 850-mb temperature, it is not the high 850-mb temperature alone that is causing the development of high ozone concentrations. Rather, the high 850-mb temperature is often an indicator of subsiding air in a high pressure system, which is usually associated with low mixing depths and clear skies and sometimes associated with warm air advection. In addition, high ozone concentrations in Santa Barbara County have been found to be correlated with pressure gradients that would suggest a wind from the southeast.

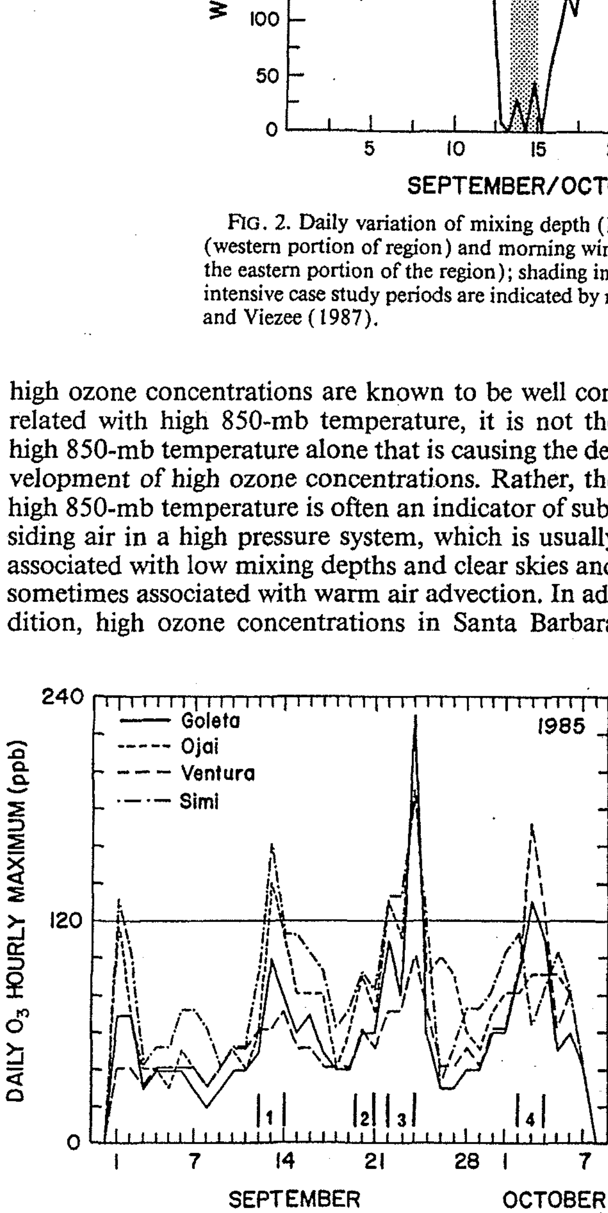


FIG. 3. Daily variation of maximum hourly surface concentration. Goleta is on the coast just west of Santa Barbara. Ventura is on the coast in the middle of the region, Ojai is in an inland valley about 15 km from Ventura, and Simi is in another inland valley about 25 km from the coast in the eastern part of the region. The intensive case study periods are indicated by the numbers 1, 2, 3, and 4. Figure taken from Dabberdt and Viezee (1987).

Analyses of the ozone concentration time series at Goleta (representative of coastal sites in the region) and the general synoptic conditions in the region during the five-week SCCCAMP 1985 period show that the ozone episodes during the SCCCAMP period occur during synoptic situations characterized by tropical cyclones approaching from the southeast, preceded by clear skies with high pressure, and usually followed by cloudy conditions. According to Cross (1988), there are typically four tropical cyclones, on the average, in the eastern North Pacific during the month of September, and their influence is often felt in southern California. The synoptic pattern of cold fronts advancing from the west, followed by clear skies, calm winds, high pressure, and occasionally punctuated by tropical cyclones advancing from the southeast is typical of September conditions on the east coast of continents in "horse latitudes" between the extratropical westerlies to the north and tropical easterlies to the south.

In a typical "idealized" 2–3 day ozone episode during SCCCAMP 1985, the first day is marked by high pressure with clear skies, light winds, low mixing depth, and high 850-mb temperature, allowing the build up of ozone in the area around local sources. The second day is marked by similar meteorological conditions, except that easterly winds begin to increase in the region marked by warm air advection on the northern fringes of an approaching tropical storm. On the third day, easterly winds spread over much of the region causing transport of polluted air masses. The episode ends when cloudiness removes the possibility of ozone formation and associated vertical mixing causes dilution of the polluted air.

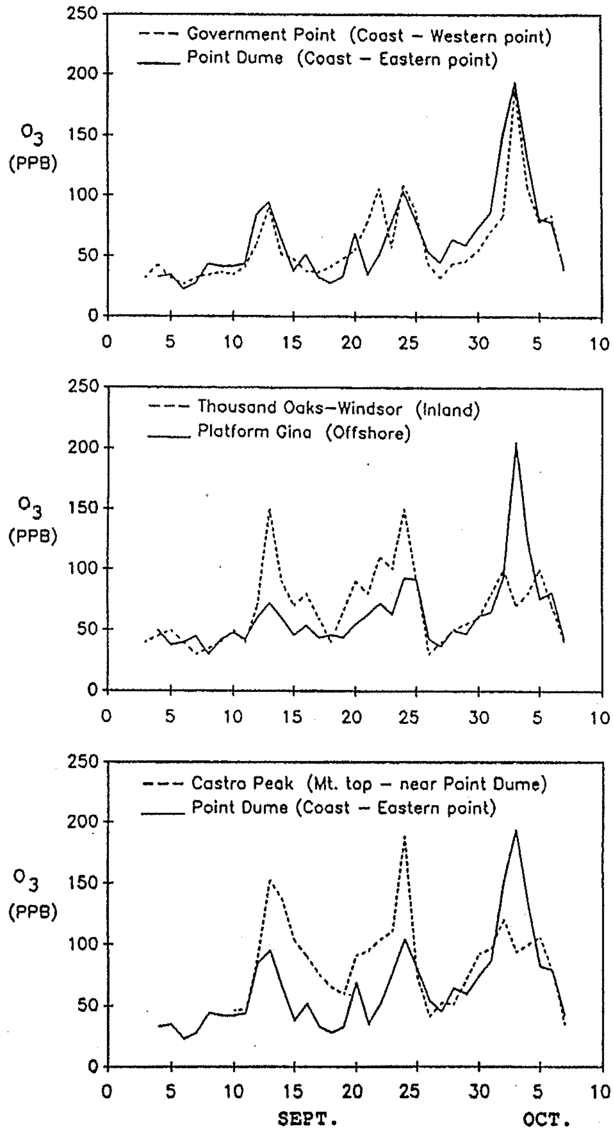


FIG. 4. Daily variation of maximum hourly surface ozone concentration, for three different pairings of stations. (Top—stations at western and eastern ends of coast; middle—stations inland and offshore; bottom—stations on mountaintop and at sea level.)

In order to illustrate the variation of mixing depth and vertical stability during the five-week period, a time series of afternoon temperature profiles observed by the Point Mugu (coastal) radiosonde is given in Fig. 5. Continuity in the mixing depth and its rate of change can be seen from day to day, and the figure verifies that the case study periods, with high ozone concentrations, are related to time periods with low mixing depths and stability in the lower atmosphere. If there were room on the figure to plot wet-bulb temperature profiles, the subsidence inversion development prior to the case study periods would be more obvious. Generally the wet-bulb temperature decreases rapidly with height in the subsidence inversion above the mixing depth.

The vertical temperature structure of the marine air is a factor in determining whether a polluted air mass flowing towards the region from the Los Angeles basin would pass mostly out to sea or would infiltrate through the inland Simi and Santa Clara valleys. During the first three case studies, the polluted air mass from Los Angeles extended to several hundred meters in height and tended to spill into the SCCCAMP region through inland valleys as well as along the coastal areas. But during case study period 4, the relatively shallow pol-

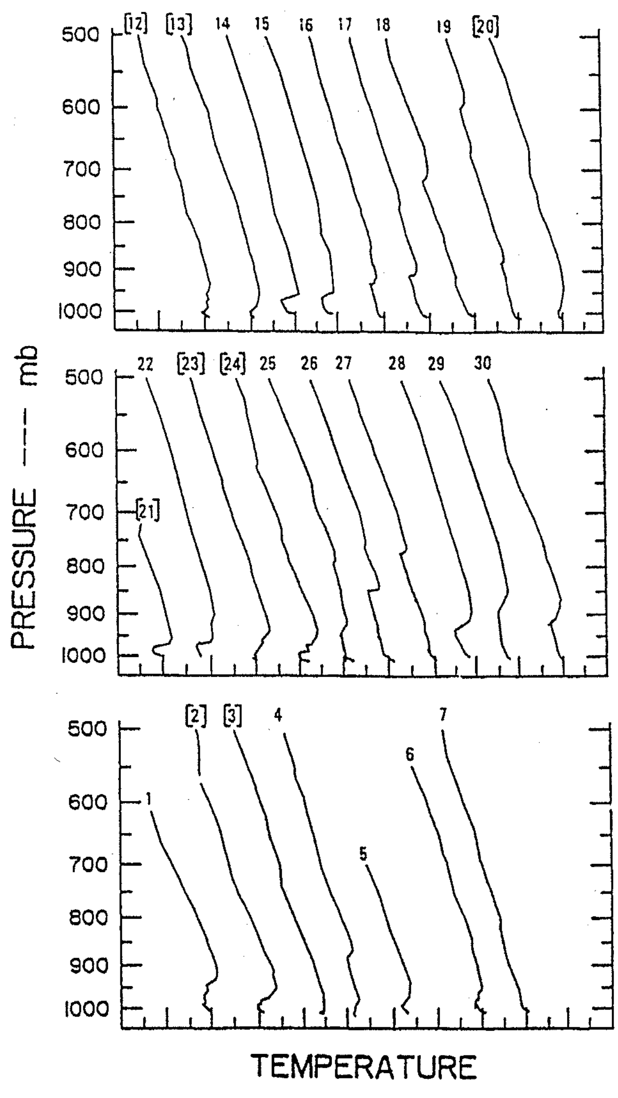


FIG. 5. Radiosonde temperature soundings in midafternoon from Point Mugu (except Vandenberg on 14–15 September, 21–22 September, 28–29 September, and Loyola on 5 October). The Loyola station is located near the coast just off the eastern edge of the map in Fig. 1. The temperature scale is 20°C between the tall hatches on the horizontal axis. Dates are indicated at the top of each sounding, and case study dates are bracketed.

luted air mass appears to have been blocked by the mountains and was forced to follow a coastal or overwater trajectory. The relatively intense stability during the last case study is not evident in the Point Mugu soundings in Fig. 5, but can be better seen looking at the average mixing depth over the region as measured by many types of sounding devices (Baxter 1991; McElroy and Smith 1991).

3. Characteristics of case study 1, 11–13 September 1985

The period between 11 and 13 September 1985, includes the only ozone episode that occurred during the first three weeks of the SCCCAMP experiment, except for 11–13 September this period was generally characterized by an upper-level trough over the region and relatively frequent cloudiness and above-normal vertical mixing. However, on 11 and 12 September high pressure moved into the region with accompanying subsiding air, clear skies, and light to moderate winds. The Point Mugu soundings in Fig. 5 show the shallow mixing depth and the subsidence inversion. The build up of photochemical pollutants on 11 September and part of 12 September appears to be caused mostly by local sources.

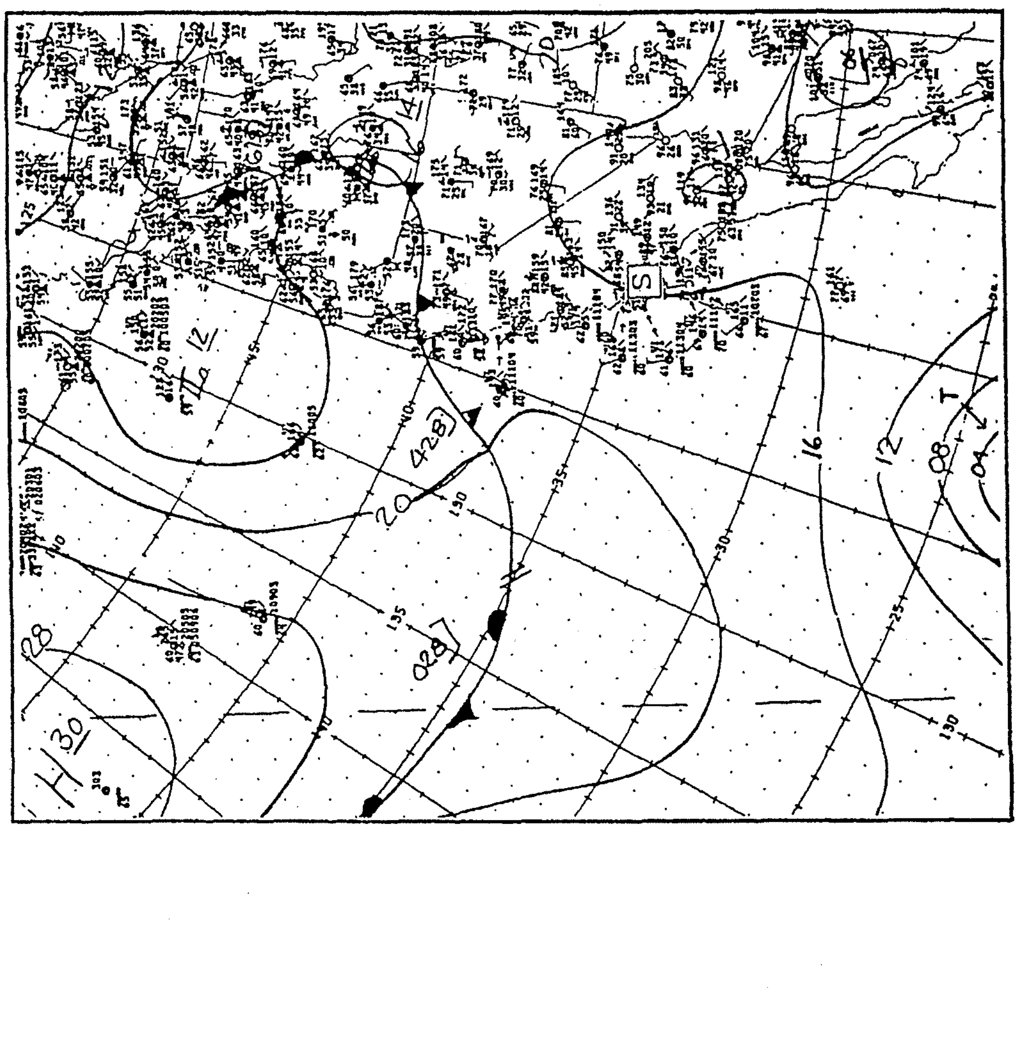
Starting on 12 September, easterly winds aloft gradually spread into the region due to a tropical cyclone approaching from the southeast, resulting in some advection of pollutants into the SCCCAMP region from the Los Angeles basin. However, westerly winds persisting in the western part of the region did not allow the advected air mass to pass very far beyond Ventura County. This situation continued through 13 September and the early part of 14 September, after the weak cold front passing through the region from the northwest broke up the episode through its strong vertical mixing and westerly winds. The synoptic situation that has just been discussed is pictured by the surface map and satellite photograph shown in Fig. 6. The cold front in northern California and the tropical storm near the southern edge of the figure are seen to be associated with extensive cloud shields.

The wind field patterns produced by a diagnostic wind analysis, based on interpolation of observed winds, are shown in Fig. 7 for local times of 0600 and 1200 PDT on 13 September (Kessler et al. 1989). An elevation of 300 m AGL is chosen for presentation because aircraft observations verify that this episode was characterized by high ozone concentrations and advection at that level. Surface wind field patterns were also produced by the diagnostic analysis, but showed much more variability than the 300-m patterns due to the influence of local terrain. These 300-m wind fields have the following characteristics:

- northerly wind components are observed over the western part in the region in the ocean off Points Arguello and Conception throughout the period,
- southwesterly flow (i.e., a sea breeze) is observed along the coast east of Santa Barbara at midday (1200 PDT), and
- easterly flow is observed along the coast and inland east of Point Conception at late night (0600 PDT).

The daily ozone concentration time series for the stations in Figs. 3 and 4 show that concentrations began increasing on 12 September, and that the 120 ppb standard was exceeded at some inland and mountaintop stations on 13 September. This band of high concentrations did not extend to the western part of the region, however (e.g., the Goleta data in Fig. 3). Concentrations were not quite as high on 14 September and then returned to lower values on 15 September following the cold front passage. Aircraft observations indicated ozone concentrations in the early afternoon on 13 September over Ventura County exceeding 200 ppb around 300–400 m above the surface, although surface concentrations were much lower (about 60 ppb). The evidence suggests that this material may have been advected into the study region along the coast from the southeast. As the mixing layer grew over land during the morning, some of the pollutants in the elevated layer were mixed to the surface. The highest concentrations in the midafternoon (1500 LST) occurred on elevated coastal terrain, although lower elevation locations in Ventura County such as Simi Valley observed ozone concentrations in excess of 160 ppb. As discussed by Killus and Moore (1991), the hydrocarbon sampling during the afternoon indicated the presence of both aged urban air and geogenic/fugitive air masses over Ventura County (geogenic/fugitive refers to naturally occurring HC seep emissions and fugitive HC emissions from oil and gas processing facilities). Halocarbon concentrations of compounds such as F_{11} (a surrogate of Los Angeles pollution) were elevated, suggesting that some of the pollution had been advected from that region. There were no exceedances of ozone air quality standards (120 ppb) in Santa Barbara County throughout the whole episode. During the afternoon, aircraft observations indicated only moderate ozone concentrations aloft over Santa Barbara with no evidence of concentrations greater than 120 ppb. During the evening the aircraft data indicate that the ozone-laden air mass at an elevation of a few hundred meters over Ventura County drifted out over Santa Barbara and the channel, but it was so late in the day that there was insufficient vertical mixing to bring it down to the surface.

The results from the tracer experiment that was conducted during the first case study period are consistent with the general features of the wind field and ozone observations (Strimaitis et al. 1991). For example, releases of two types of tracer gas were made from platform Hondo, in the western part of the Santa Barbara Channel, in the early morning on 13 September. The tracer clouds were observed to move onshore with the



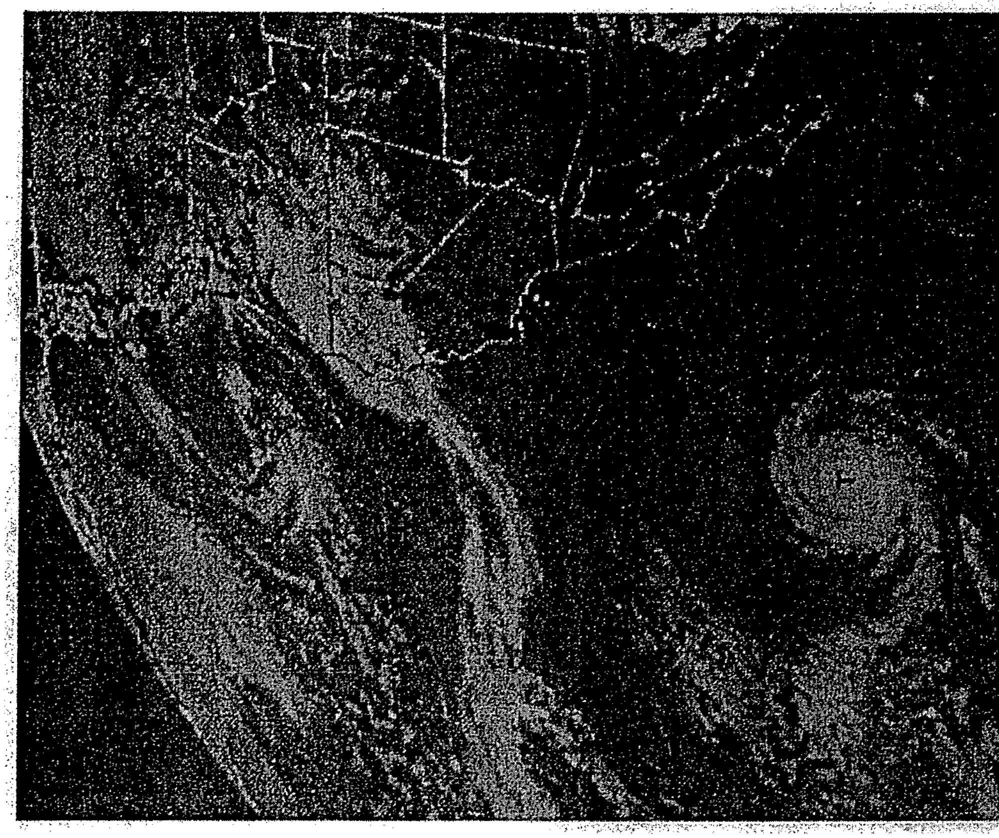


FIG. 6. Surface weather map (1700 PDT) and satellite photograph (1501 PDT, 4 km, visible) for 13 September 1985 (from Viezee et al. 1987). The SCCCAMP region is marked by an "S" and the position of the tropical storm is marked by a "T" on both maps.

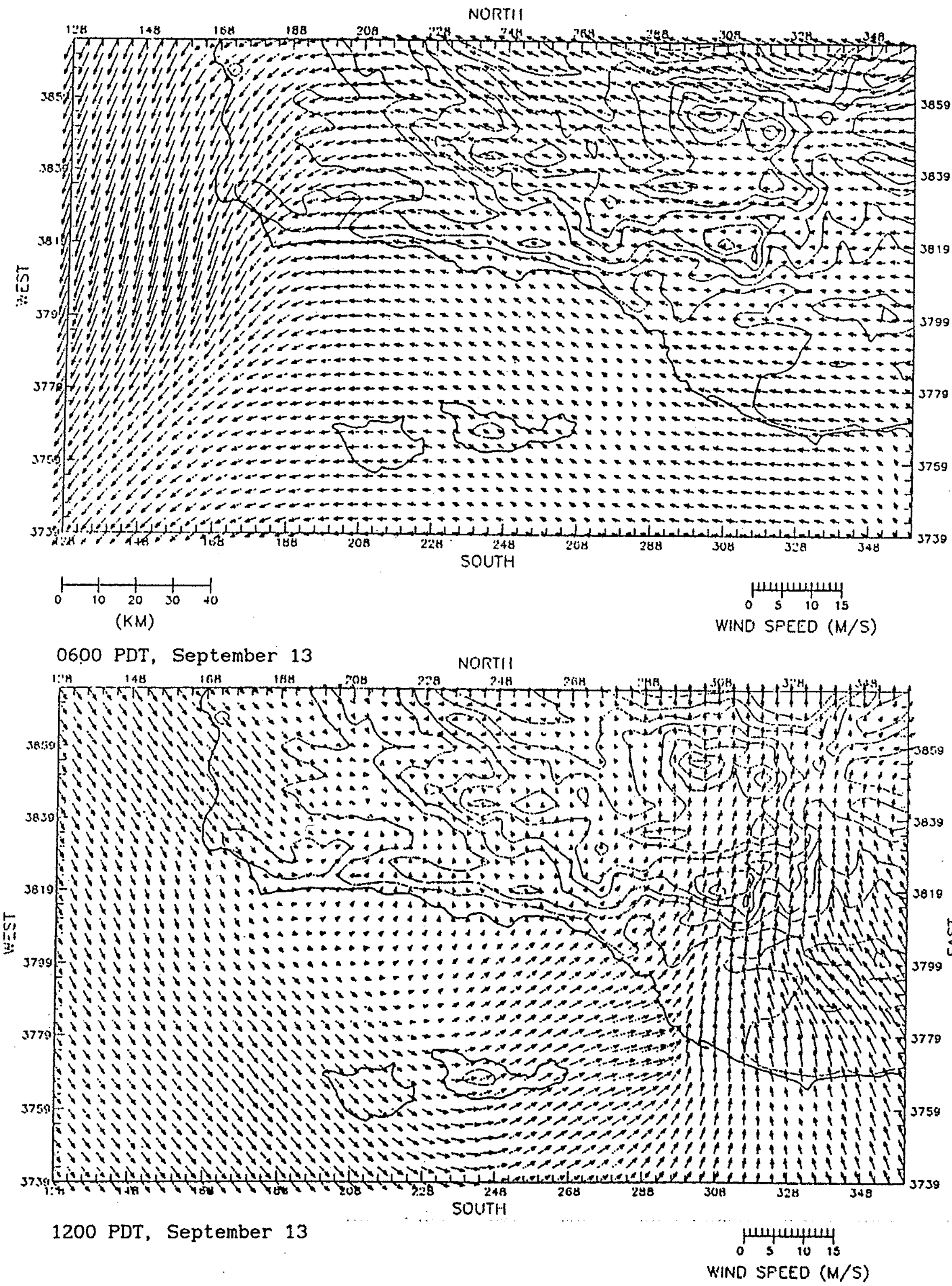


FIG. 7. Interpolated observed wind fields at an elevation of 300 m for 0600 (a) and 1200 PDT (b) on 13 September for the first case study period (from Kessler et al. 1989).

sea breeze during the day and then moved offshore with the land breeze in the evening. Another tracer release took place from R/V *Acania* off Government Point in the western part of the region, but this tracer was caught in the northwesterly flow over the ocean and was advected to the south and east of the SCCCAMP region.

4. Characteristics of case study 2, 20–21 September

Case study 2, including 20 and 21 September, was associated with a transition between the upper-level trough that covered the SCCCAMP region during the first part of September and the upper-level ridge that formed for the remainder of the five-week study. A surface high with associated low mixing depth and strong subsidence inversion (see the vertical temperature profiles in Fig. 5) was centered over the region. No major easterly flow patterns developed during this case study period. The synoptic situation during case study 2 is pictured in Fig. 8, showing the usual persistent northerly flow component at the surface over the ocean and the light winds at the coastal stations. Hurricane Terry is visible on the satellite photograph as a spiral of clouds at a location off the tip of Baja California. The storm is not yet near enough to influence the winds in the boundary layer in the SCCCAMP region, and the 300-m wind velocities on the interpolated observed wind field displayed in Fig. 9 show the influence of the sea- and land-breeze cycle along the Santa Barbara and Ventura coastal region. Channeling of the flow by the coastal mountains can be seen in most regions.

Moore et al. (1991) state that on 21 September, the nitrous oxide (NO) and nitrous dioxide (NO_2) concentrations in the early morning were typical of those from isolated and local influences (e.g., isolated morning NO maximum at Santa Barbara and Simi Valley). The morning peak NO_2 concentration at Simi Valley was only 40 ppb. Areawide carbon monoxide (CO) concentrations were not significantly elevated on either day of the episode, suggesting a lack of transport from Los Angeles. The peak concentrations occurred primarily at sites in Santa Barbara located near main roads, due to emissions from local traffic.

Because this period was marked by a typical diurnal sea- and land-breeze cycle and the general offshore flow was out of the northwest, this case study period was the mildest of the four case study periods in terms of peak ozone concentrations. For example, ozone concentrations in Santa Barbara did not exceed 70 ppb during the whole episode. The maximum ozone concentrations occurred over a broad region of the inland portion of Ventura County, but were limited on both days to 60–100 ppb, which is below the air quality standard of 120 ppb. Aircraft spirals made during 20 and 21 September revealed only slightly elevated (40–70 ppb) ozone concentrations aloft. During the morning of 21 September there was actually a significant ozone depletion over the first 800 m above the surface due to chemical reactions with NO_x. The ozone concentration time series at individual monitoring stations during case study period 2 were similar to those during case study period 1, as seen in Fig. 4. Offshore concentrations were about 60%–70% of inland concentrations, and low-level concentrations were about 50% of those on mountaintops.

The fixed and aircraft hydrocarbon observations showed relatively clean air offshore [maximum nonmethane hydrocarbon (NMHC) < 100 ppb] on both days (Killus and Moore 1991). Other sampling sites showed an influence of local emissions of hydrocarbons, with no evidence of large contributions of hydrocarbons from distant source regions.

The tracer cloud movements for early morning releases on 20 September from an offshore platform in the western portion of the region and from the Mandalay power plant site (along the eastern coast) agree with the observed wind fields (Strimaitis et al. 1991). The tracer release from the platform moved offshore briefly in the early morning when it was still influenced by the land breeze, then came onshore with a southwesterly sea breeze during the later morning and afternoon. During the night, it was transported back out to sea by the land breeze. The release from the Mandalay power plant followed the same pattern, but was advected out of the region to the east by the next day.

It can be concluded that case study period 2 produced the least serious air pollution concentrations of the four case studies, with most of the ozone observed in the SCCCAMP region generated by local sources. The region was dominated by moderate high pressure with a subsidence inversion and typical sea- and land-breeze patterns.

5. Characteristics of case study 3, 23–25 September

A significant ozone episode occurred in the region during case study 3 on 23–25 September as shown by the ozone concentration time series in Figs. 3 and 4. High pressure with subsidence and a typical sea-breeze cycle was followed by light easterly flow on the northern reaches of Tropical Depression Terry. Consequently, the polluted air mass that occupied the mixed layer in the eastern part of the region (i.e., the Los Angeles basin) was advected over the western part of the region by the second day of the episode. It also should be mentioned that case studies 2 and 3 are both part of a several-day ozone episode, and that ozone was continually building up in the region from 20 through 24 September. Figure 10 displays the surface weather map and the satellite photograph for 24 September. There were many clouds around the storm, which was centered about 400 km to the south-southwest of the SCCCAMP region, but the SCCCAMP region itself remained in clear air. The Los Angeles surface temper-

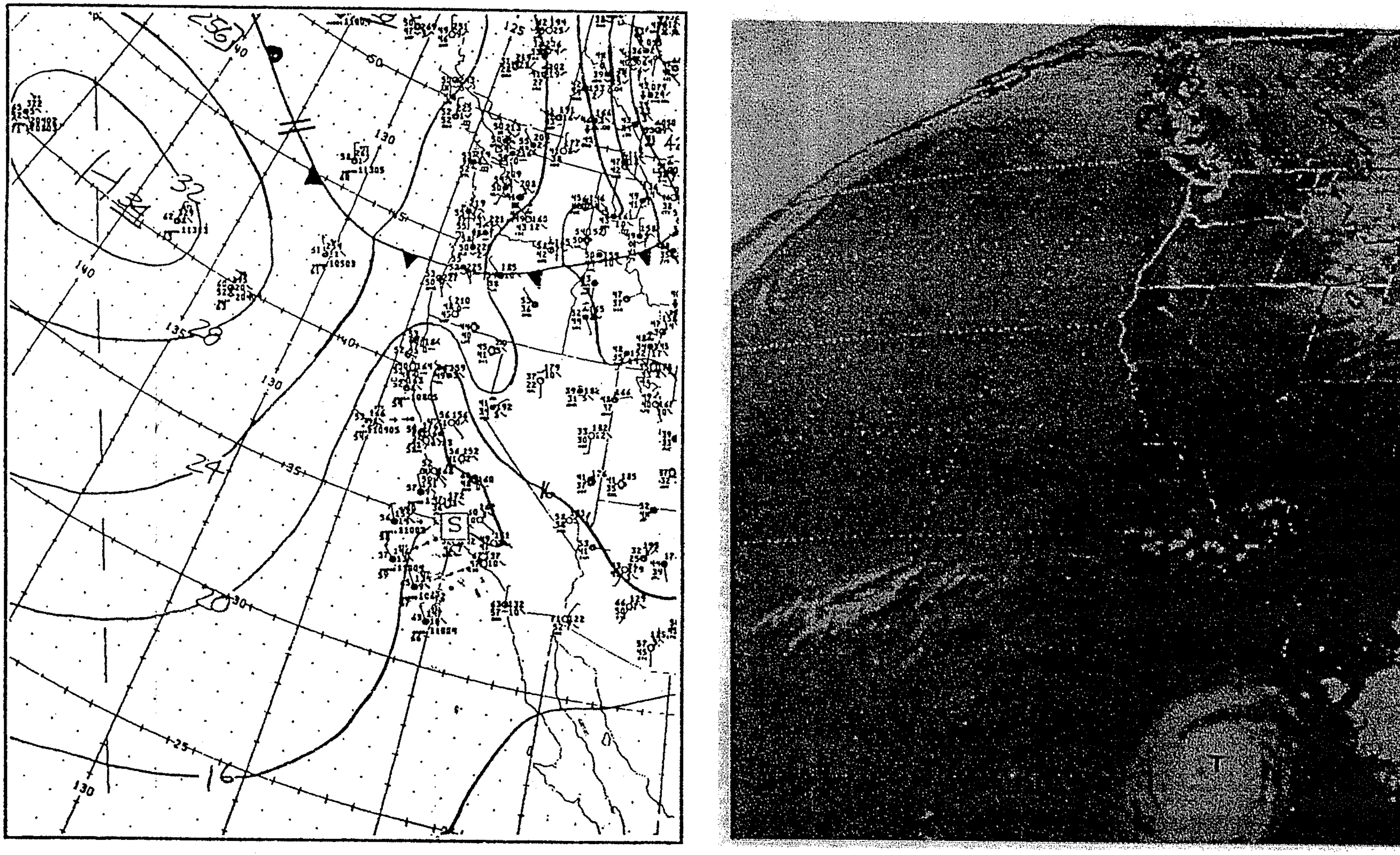


FIG. 8. Surface analysis (0500 PDT) and satellite photograph (1401 PDT, 4 km IR) on 21 September 1985 (from Viezee et al. 1987). The SCCCAMP region is marked by an "S" and the position of the tropical storm is marked by a "T" on the satellite photograph.

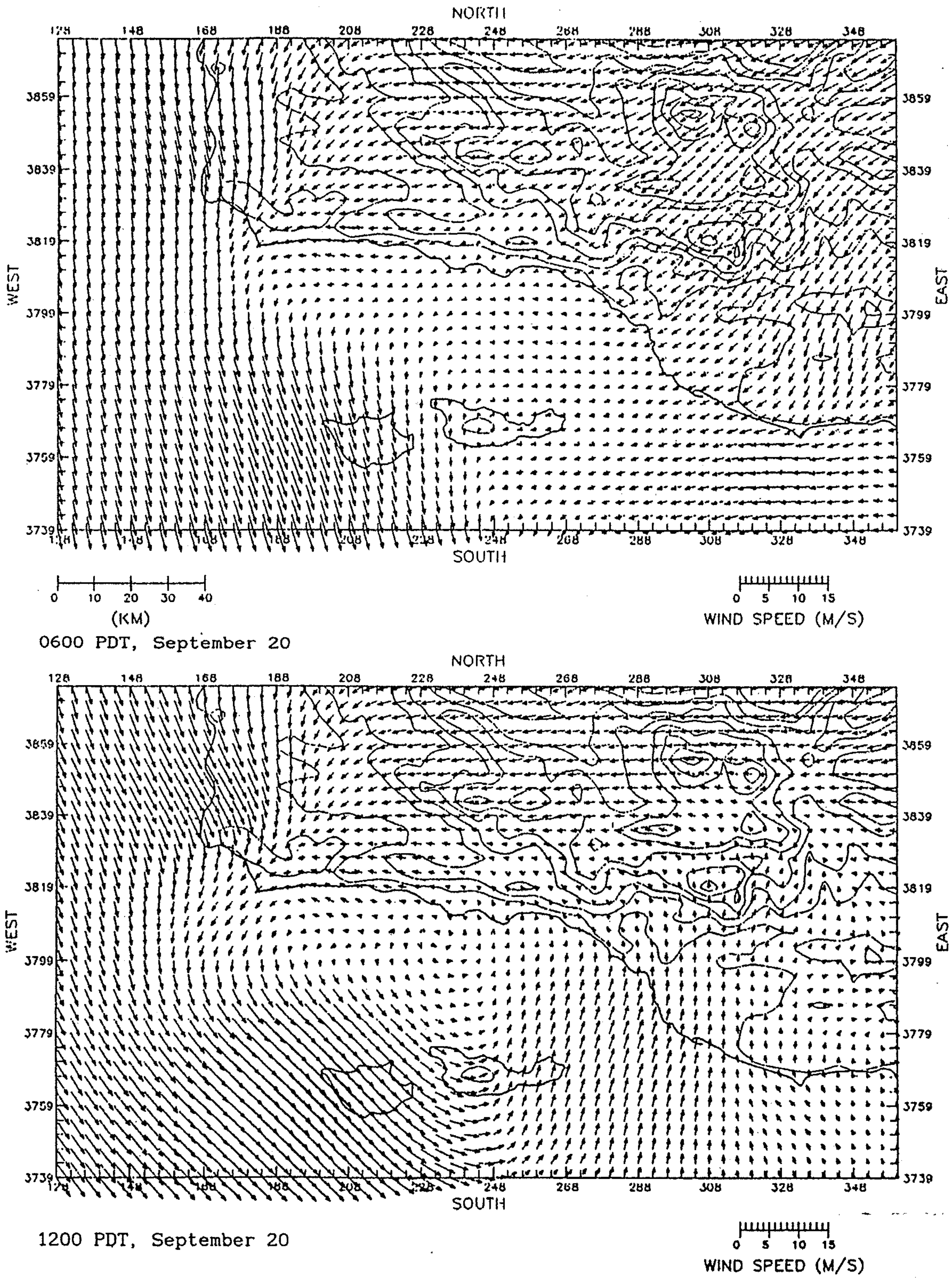


FIG. 9. Interpolated observed wind fields at an elevation of 300 m for 0600 (a) and 1200 PDT (b) on 20 September for the second case study period (from Kessler et al. 1989).

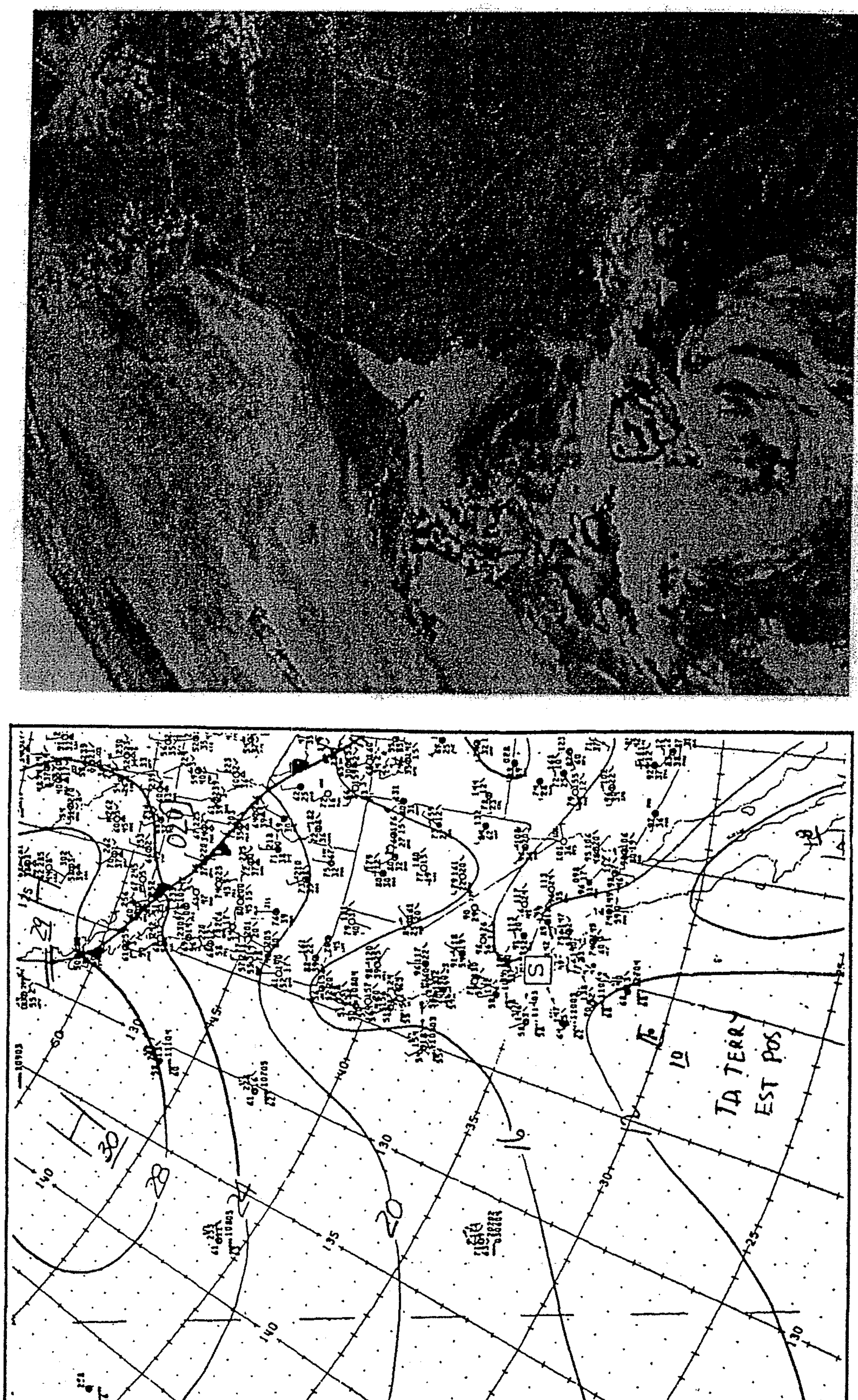


FIG. 10. Surface weather map (1700 PDT) and satellite photograph (1101 PDT, 2 km, visible) for 24 September 1985, during case study 3 (from Viezee et al. 1987). The SCCCAMP region is marked by an "S."

ature and 850-mb temperature on this day were the highest recorded during the month. The combination of low mixing depths, high temperatures, clear skies, and light easterly winds was ideal for ozone formation throughout the SCCCAMP region.

The interpolated observed wind field at the 300-m elevation is shown in Fig. 11 for 0600 and 1200 PDT on 24 September. On the previous day, the usual north-to-northwest flow persisted in the western part of the domain, with light southerly or easterly flow in the eastern part. The sea- and land-breeze cycle was more evident on the 23d. As shown in Fig. 11, by 1200 PDT on the 24th moderate easterly winds covered nearly all of the domain. The episode ended abruptly on 25 September as air marked by cloudy skies with increased vertical mixing entered the region. The time series of radiosonde soundings in Fig. 5 also illustrate the change in vertical mixing potential, showing a strong subsidence inversion on 23 and 24 September, and a deepening well-mixed layer on 25 through 27 September.

Ozone concentrations at the surface in Ventura County on the 23d were about 60 ppb at 0800 PDT in the morning (Moore et al. 1991). At the same time, the local NO maxima at Santa Barbara and Simi Valley were already twice the concentrations observed during 20 and 21 September (Simi Valley > 150 ppb). By 1300 PDT a broad range of ozone concentrations in excess of the air quality standard (120 ppb) was observed throughout Ventura and Santa Barbara counties. The band of maximum concentrations extended westward from Simi Valley, where the areawide peak concentration was observed. Peak ozone concentrations occurred during the next two hours. In some inland and elevated areas the high ozone concentrations persisted until after 1700 PDT.

Nonmethane hydrocarbon (NMHC) concentrations offshore during 23 September were about 250 ppb or larger during the morning, but dropped to clean air levels during the afternoon as a result of both chemical breakdown and the sea breeze (Killus and Moore 1991). In interior regions of Ventura County the NMHC concentrations systematically increased during the day, reaching a value of 1068 ppb by 1500 PDT at El Rio. The aircraft flights showed substantial daytime increases of ozone up to a height of 1500 m in the interior of Santa Barbara County. Aircraft spirals offshore indicated that ozone concentrations of up to 150–200 ppb were encountered in the 200–400 m layer during the afternoon. This layer was cut off from the surface because it was very stable with limited vertical mixing.

During the morning of 24 September the surface ozone concentrations were not unusually large, but ozone concentrations of 60 ppb found at stations on elevated terrain, such as Laguna Peak, suggest that high ozone concentrations existed aloft. Moore et al. (1991) point out that the surface ozone concentration rapidly increased throughout the day, with exceedances of the ozone standard occurring at 1300 PDT at Santa Barbara and half a dozen sites in Ventura County. Most of these exceedances were found in the southeast corner of the SCCCAMP study region. By 1500 PDT the maximum ozone concentrations occurred in Santa Barbara County and western Ventura County with maxima of 180–200 ppb. Later the ozone maximum moved further west to the Santa Ynez airport.

On 24 September, CO concentrations at inland sites such as El Rio reached 1000 ppb during the afternoon, the highest reading during the whole episode. The chlorofluorocarbon-12 concentrations (an indicator of an urban air mass) also reached their highest levels during the afternoon of the 24th (800 ppt versus a regional background of 500 ppt). Similar peaks in several other inert tracers suggest that air from a distant region with higher background levels of these tracers may have been contributing to the local observed concentrations.

The ozone levels aloft increased substantially during 24 September from an initial 100 ppb to 150–200 ppb (Moore et al. 1991). Over land, the layer with the greatest ozone concentrations extended from the surface to a mixing height of about 800 m over Ventura County. Over water, the layer with high ozone concentrations extended from 100 to 500 m. At the water surface, observed ozone concentrations were not particularly high, suggesting that there was little downward mixing from the stable air mass aloft. During case study 3, as during case studies 1 and 2, ozone concentrations tended to be as high on coastal mountaintops as in nearby inland valleys and tended to be higher inland than offshore (see the ozone concentration time series in Fig. 4). Case studies 1 and 3 each showed shoreline ozone concentrations higher in the eastern part of the domain on the first day of the episode, followed by nearly equal values on the second day of the episode. Presumably this equalization was caused by the advection of pollutants from east to west due to easterly winds on the second day.

Tracers were released in the early morning of 24 September from an offshore oil platform in the western part of the region and from an aircraft at 600-m elevation over the San Fernando Valley (Strimaitis et al. 1991). By midmorning, the release from the offshore oil platform was advected onshore by southeasterly winds, and the release from the aircraft was carried to the west in the easterly wind flow evident in Fig. 11. The interpolated observed surface wind field pattern for this period does indicate south winds near the oil platform in the afternoon, in agreement with the observed tracer trajectory.

It can be concluded that case study period 3 was representative of an ozone episode in the SCCCAMP region. The episode began with a day dominated by a high pressure system with subsidence, clear skies, hot temperatures, and light winds. As a result, ozone concentrations increased due to local sources on the first day of the episode. However, advection from the eastern part of the region on the second day led to high

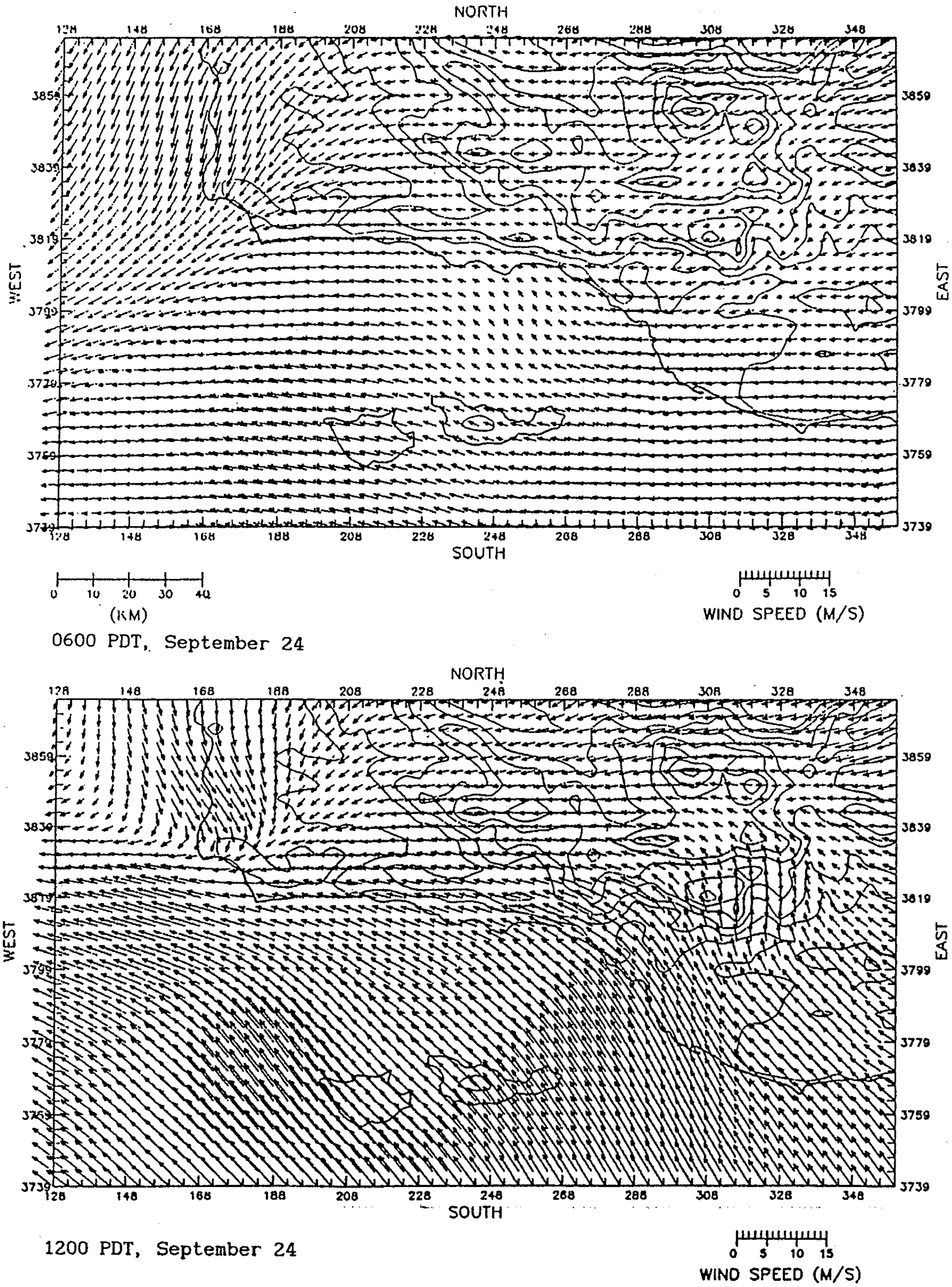


FIG. 11. Interpolated observed wind fields at an elevation of 300 m for 0600 (a) and 1200 (b) PDT on 24 September for the third case study period (from Kessler et al. 1989).

ozone concentrations resulting from emissions from a combination of local and distant sources. The advection occurred along both the coastal and inland paths and extended vertically to heights of several hundred meters. By the end of the episode, high ozone concentrations reached Santa Ynez, but did not penetrate very much into the Vandenberg/Lompoc area in the far western part of the region. The episode ended as clouds from Tropical Storm Terry entered the region.

6. Characteristics of case study 4, 2–4 October

The fourth case study period, on 2–4 October, was the most unusual of the four since very low mixing depths and easterly winds resulted in advection of pollutants from the Los Angeles basin out over the ocean and low-lying coastal plains. This advected air mass combined with local sources to cause ozone observations to exceed National Ambient Air Quality standards in the SCCCAMP region (see the ozone time series in Figs. 3 and 4). The highest concentrations of the entire SCCCAMP period were observed at most offshore and coastal stations during case study 4, and these high concentrations extended over the westernmost monitoring locations. Ozone concentrations were relatively low at inland and mountaintop monitors. As in the previous three case studies, this case study was associated with a tropical depression approaching from the south.

The surface weather map for 1700 PDT 3 October in Fig. 12 shows high pressure over the ocean to the northwest and a tropical depression over the ocean several hundred kilometers to the south. The cyclonic motion around the tropical depression is very evident in the satellite photograph, which suggests that a broad cloud bank exists just to the south of the SCCCAMP region. In fact, these clouds spread over the region on 4 October, causing increased vertical mixing (see the radiosonde time series in Fig. 5) and resulting in a reduction of ozone concentrations in the polluted air mass that had hugged the shoreline during the previous two days.

On 2 October dominant northwest winds persisted over the Vandenberg area and over the ocean off Point Arguello (Kessler et al. 1989). Farther to the east on this day the winds were light out of the northeast. The interpolated observed wind fields at a nominal height of 300 m are plotted in Fig. 13 for times of 0600 and 1200 PDT 3 October. As seen in the figure, on 3 October the entire domain was covered by winds with a component from the east, even overpowering the tendency towards northwest flow off Point Arguello. Coincidentally, this is the only day during the five-week SCCCAMP period that ozone concentrations exceeded 100 ppb at Vandenberg, at the far western edge of the domain.

Because the mixing heights were very low during the 2–4 October episode (Baxter 1991), there was a buildup of local emissions of halocarbons and hydrocarbons along the California coastal region on 2 October and on the coast and offshore on 3 October. An easterly wind early in the morning of 3 October appeared to move a large pool of polluted air trapped near the surface out into the ocean off Los Angeles. Moore et al. (1991) point out that aircraft observations on 3 October suggest that this reservoir of polluted air was then moved to the northwest by southeasterly winds during the day. According to surface ozone observations, this air mass extended at least as far southwest as San Miguel. Air chemistry observations suggest that substantial amounts of halocarbon-enriched air moved into the study region from the south at elevations of 100–200 m. Halocarbon (F_{12}) concentrations, which were found to have the least time or spatial variability of all the air chemistry measurements, nearly doubled from the nonepisode background values to rival those typically observed in Los Angeles (Hester et al. 1974). During 3 October the hydrocarbon speciation most closely resembled that of an urban environment (Moore and Killus 1991). However, the hydrocarbon data suggested that in addition to the aged urban component, there seemed to be a competing geogenic/fugitive component. The net result was that some of the largest $NMHC/NO_x$ ratios of all the episodes were observed.

Aircraft observations verified that this polluted air mass was shallow, extending only up to 200 m (Moore et al. 1990). In the late afternoon on 3 October the ozone-enriched air moved into the coastal regions of both Santa Barbara and Ventura counties. Because of the structure of the sea breeze on that day, the ozone-enriched air mass did not penetrate very far inland, and, therefore, did not significantly increase ozone concentrations aloft over the interior of either Santa Barbara or Ventura counties. High coastal ozone concentrations were observed by the aircraft along the entire coastline as far west as Point Conception.

As shown by Strimaitis et al. (1991), the observed movement of tracer clouds agreed with the above wind field and ozone interpretations, since the tracer clouds also tended to hug the coast and move generally from east to west. For example, the tracer clouds that were released from the surface near the Mandalay power plant and from platform C on the previous afternoon were observed along the shoreline between Gaviota and Point Dume in the early morning on 3 October. These clouds were being advected by the easterly flow, which was being augmented by the land breeze in the early morning.

It is concluded that the episode detected during case study 4 was primarily caused by the advection of a shallow mass of polluted air by easterly flow from the Los Angeles basin into the Santa Barbara Channel. High ozone concentrations over the water and along the shoreline were, therefore, mostly due to distant sources. Moderate ozone concentrations observed in inland valleys were probably due to local sources, since

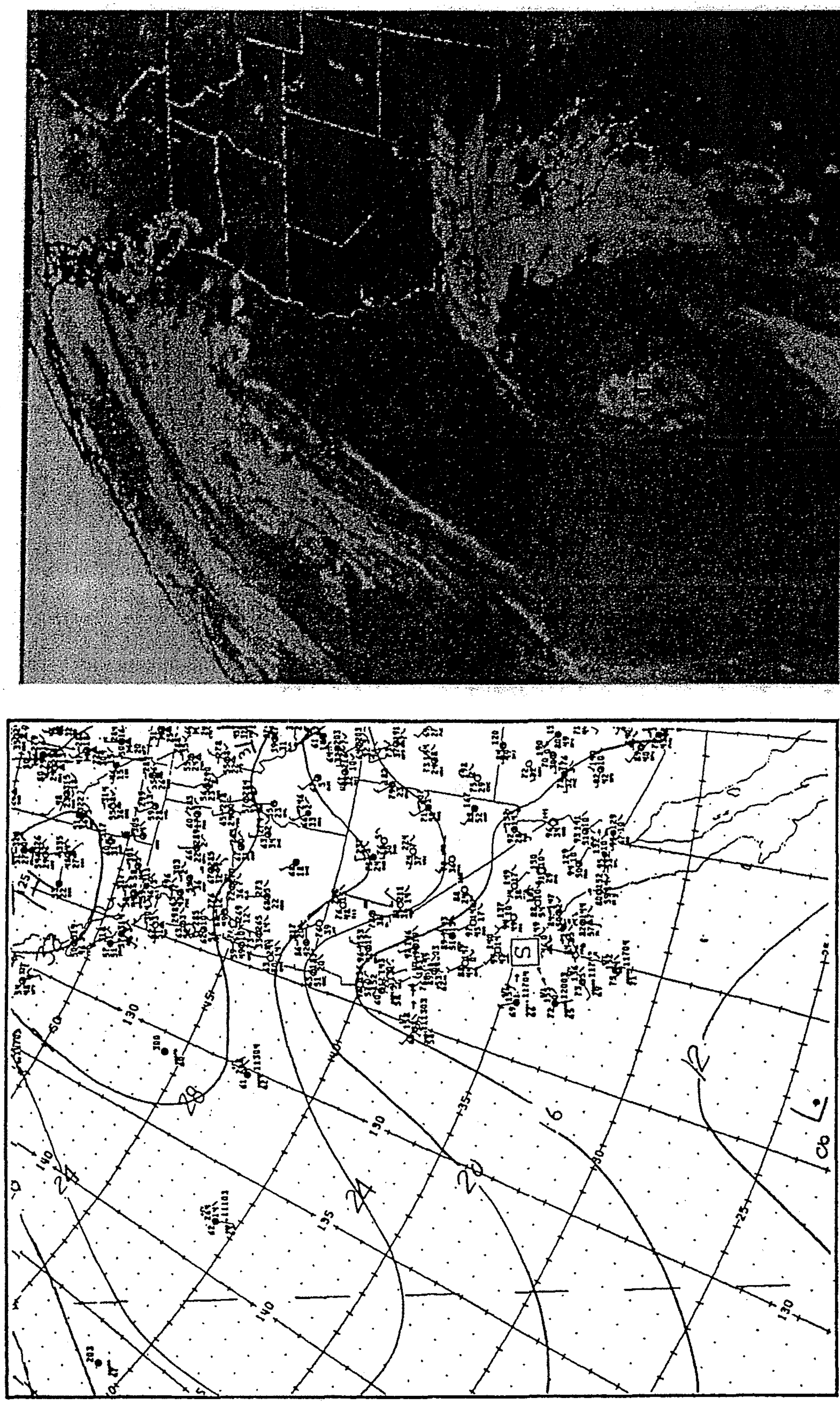


FIG. 12. Surface weather map (1700 PDT) and satellite photograph (2100 PDT, 4 km, IR) for 3 October 1985 (from Viezee et al. 1987). The SCCCAMP region is marked by an "S." The spiral of clouds around the tropical depression is seen in the satellite photograph.

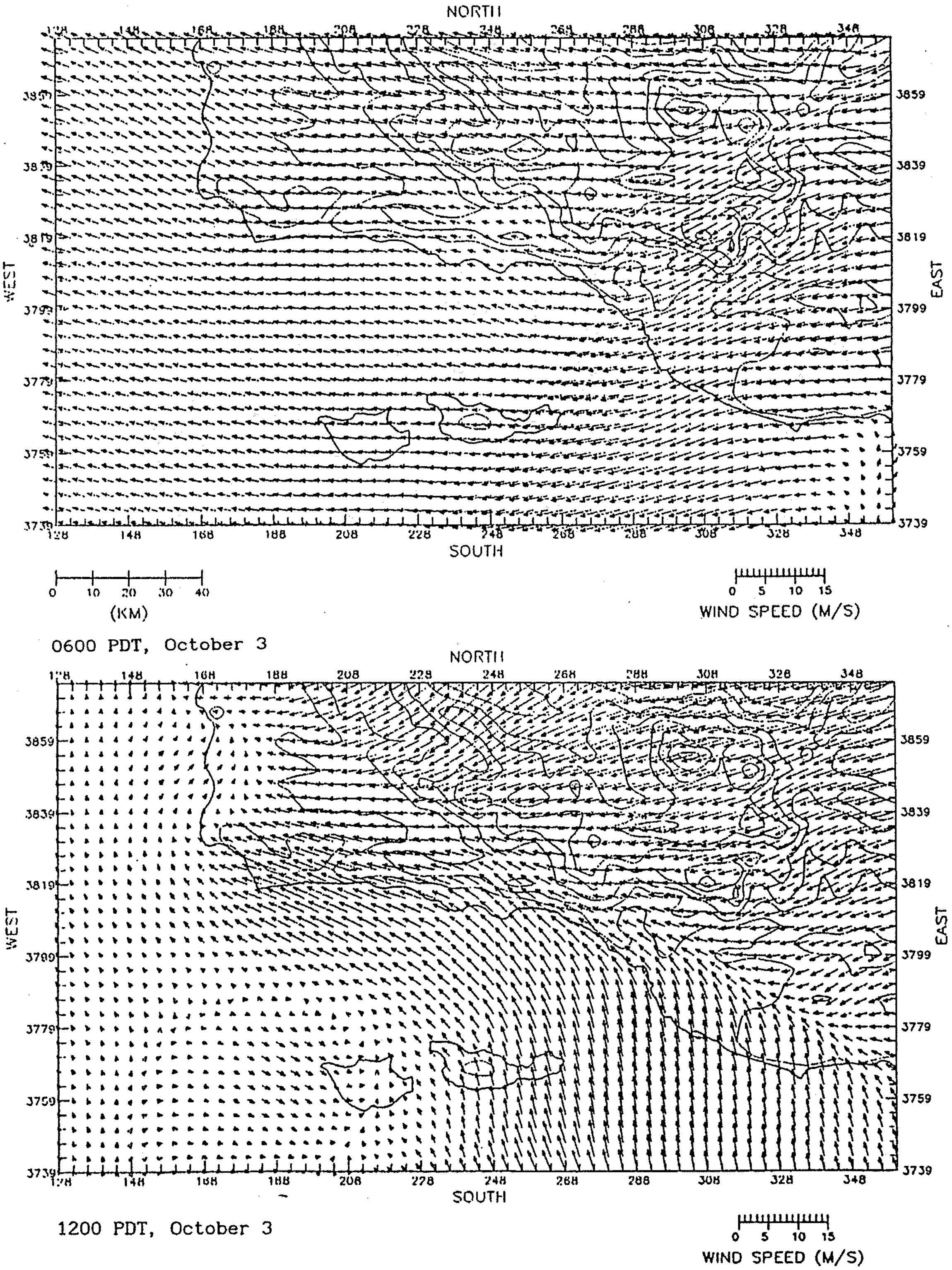


FIG. 13. Interpolated observed wind fields at an elevation of 300 m for 0600 (a) and 1200 (b) on 3 October for the fourth case study period (from Kessler et al. 1989).

the polluted air mass was not able to penetrate past the first coastal range.

7. Summary of four intensive case study periods

The previous sections have described the detailed results of the four intensive case study periods. A brief summary of each of the four intensive case study periods is given in the following text.

a. Case study 1, 11–13 September

The 120-ppb ozone standard was exceeded at some inland and mountaintop stations in Ventura County on 13 September. This case study is an example of an episode caused partly by the emissions from local sources when the region is under the influence of a stable high-pressure system, and partly by polluted air advected from source regions to the east (i.e., Los Angeles). Typical sea-breeze recirculation patterns existed on 12 September. This flow pattern was slightly perturbed on 13 September by a southeasterly flow in the eastern part of the region, resulting in the advection from the Los Angeles area of a pollution tongue with ozone concentrations of about 200 ppb at a height of 300–400 m above the surface. This polluted air mixed down to the surface in inland areas of Ventura County. The episode ended on 14 September as a cold front passed through the region.

b. Case study 2, 20–21 September

No ozone exceedances were observed during this case study, which was similar to the first case study, with the exception that no significant easterly flow developed aloft. A typical sea-breeze pattern was evident, as the region was influenced by high pressure. It appears that local sources dominated the observed ozone patterns.

c. Case study 3, 23–25 September

The third case study was actually a continuation of the second case study. Large exceedances of the ozone standard were observed throughout Ventura County and many parts of Santa Barbara County, as concentrations reached values of 200 ppb. An easterly flow developed during this case study, as the high pressure was slowly displaced by the northerly fringes of Tropical Depression Terry as it approached from the southeast. The easterly flow during case study 3 extended farther to the west and persisted for a longer time than during case study 1. However, the persistent northwesterly flow off Point Arguello was not perturbed during this case study. Furthermore, some evidence of the sea breeze was seen on each day. Again, the effects of local sources were compounded by a tongue of ozone-rich air that was advected along the coast and inland at elevations of 200–400 m. Observed ozone concentrations were nearly equal on coastal mountaintops and inland valleys. The episode ended on 25 September as clouds from Tropical Depression Terry spread over the region.

d. Case study 4, 2–4 October

This case study was unique in that very low mixing depths and easterly winds caused the advection of pollutants from the Los Angeles basin out over the ocean and low-lying coastal plains. There was no elevated tongue of pollutants at inland locations, as in case studies 1 and 3. As in previous case studies, this one began with strong high pressure, clear skies, and light winds; causing the buildup of pollutant concentrations due to local sources. By 3 October, easterly winds spread over the entire region, even overwhelming the northwesterly flow off Point Arguello. This is the only time during any of the case studies that high ozone concentrations extended as far west as Vandenberg. The ozone standard was exceeded at most offshore and coastal stations on that day. During the afternoon, a southerly sea-breeze perturbation developed that advected the polluted air mass into coastal areas. There is little question that this episode was caused mainly by advection of pollutants from the Los Angeles basin.

Acknowledgments. This report is based on analyses of the SCCCAMP 1985 data carried out by a number of scientists and has benefited from extensive technical reviews of oral and draft reports conducted by the SCCCAMP committee composed of over 20 scientists from various government agencies, industries, universities, and other research groups. We appreciate Mr. Thomas Chico's guidance as Minerals Management Service (MMS) Project Manager over the duration of this project. In addition, we appreciate the assistance of Mr. Roy Endlich, Mr. William Viezee, and their associates of SRI International in answering our questions concerning the SCCCAMP 1985 Data Archive.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

December 5, 1996

Richard H. Baldwin
Air Pollution Control Officer
Ventura County Air Pollution Control District
669 County Square Drive
Ventura, CA 93003

Dear Mr. Baldwin:

Per a request from the U.S. Navy, I am writing to clarify the attainment classification status of San Nicolas and Anacapa Islands. We understand that the District's Air Pollution Control Board specifically exempted San Nicolas Island from the Air Quality Management Plan requirements, pending a formal determination from EPA that San Nicolas Island is not part of the Ventura County federal ozone nonattainment area.

As you know, Anacapa and San Nicolas Islands are part of Ventura County. However, the Ventura County ozone nonattainment area comprises all of Ventura County except for the Channel Islands, which are designated as unclassifiable/attainment in the South Central Air Basin. Therefore, although part of Ventura County, the Anacapa and San Nicolas Islands are not part of the Ventura nonattainment area. If you have any additional questions or comments, please contact Julia Barrow, Chief of the Planning Office, at (415) 744-1230.

Sincerely,

for

David P. Howekamp
Director
Air Division

cc: Lynn Terry, ARB
Scott Johnson, VCAPCD
Henry Hogo, SCAQMD
Hasan Jafar, US Navy, Pt. Mugu

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